Continental J. Renewable Energy 2 (1): 1 - 6, 2011

http://www.wiloludjournal.com
Printed in Nigeria

CHARACTERIZATION AND PERFORMANCE EVALUATION OF 11M^3 BIOGAS PLANT CONSTRUCTED AT NATIONAL CENTER FOR ENERGY RESEARCH AND DEVELOPMENT, UNIVERSITY OF NIGERIA, NSUKKA.

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ABSTRACT
An 11M^3 Chinese- type fixed dome biogas plant, designed and constructed at the National Center for Energy Research and Development, University Of Nigeria, Nsukka was characterized through measurement of its actual volume and intensive three (3) weeks kitchen performance tests. Results of the measurement of the plant showed that its actual volume is 11.0M^3. Anaerobic digestion of cow dung using the plant was carried out. The plant was found to utilize 2000kg of the waste with 4000kg of water giving a waste to water ratio of 1:2. The experiment under semi-continuous batch process was carried out within a retention period of 90 days and mesophilic temperature range of 26°C and 38°C. The volume of gas production at full capacity of the plant was found to be 1.13 L / kg. TS with pressure of 0.147 bar. Food items commonly consumed in the environment such as eggs, rice and stew, yam, normal and hard beans ("fio-fio"), soup flavouring agent ("Okpei") were utilized for the cooking performance tests at full production capacity and at various volumes of gas in the biogas plant. Overall results showed that at full capacity, cooking can take place for 5hr at a stretch no matter the food item being cooked. The plant also has the capability to serve a family of 8 persons averagely on a daily basis.

KEYWORDS: Biogas plant, biogas production, biogas yield, cooking test, fixed dome digester.

INTRODUCTION
The rising cost of petroleum products is a serious problem facing most developing countries of the world including Nigeria. Again, excessive energy demands from both rural and urban dwellers imply that other natural sources of energy have to be explored. Hence, conversion of agricultural wastes into biogas could be a leeway to solving some of these energy problems. In the developing countries, majority of the populace are rural and sub-urban dwellers without access to gas for cooking and electricity (Matthew, 1982). This has contributed immensely to the rapid rate of deforestation and desert encroachment. The establishment of biogas plants in these communities is expected to greatly ameliorate these problems and help preserve the environment (Bori et al., 2007). Biogas is a mixture of gases consisting mainly of methane (50 – 70%), CO_2 (20 – 40%) and traces of other gases like CO, H_2S, NH_3, O_2, H_2, N_2 and water vapour etc. (Edelmann et al., 1999). The effluent of this process is a residue rich in essential inorganic elements like nitrogen and phosphorus needed for healthy plant growth known as biofertilizer which when applied to the soil enriches it with no detrimental effects to the environment (Bhat et al., 2001). A biogas plant is an airtight container where biogenic wastes when diluted with water are fermented by bacteria in the absence of oxygen (Richie, 1983). The plants could be made out of concrete, steel, brick or plastic. They could also be in shape like silos, troughs, basins or ponds and may be placed underground (pit) or on the surface. Many countries such as India, China, Taiwan, and Nigeria among others have built biogas plants (biodigesters) based on cow dung (Chonkar, 1983, Van Buren, 1979, Bryant, 1979, Energy Commission, 1997). However, the sizes, shapes, constructional materials etc vary. Hence there is need to characterize the different biodigesters. Since the main objectives of biogas technology is to generate energy and provide rich- nutrients manure, cooking test is highly imperative, as fossil- based fuels become scarce and more expensive. This research was carried out to characterize the underground fixed dome biogas plant constructed at the National Center for Energy Research and Development, UNN in terms of actual volume (at full capacity and on a daily basis) and its cooking ability. The common food items consumed in the South Eastern Zone of Nigeria ranging from the easily cooked ones (such as eggs, rice, stew and yam) to the harder to cook ones (like normal and hard beans- "fio fio", soup flavouring agent- "Okpei") were utilized for the cooking. Also tests were carried out at full capacity of the gas and at various volumes of the gas in the biogas plant. Cow dung was used to evaluate the biogas plant under semi-continuous batch process for a period of 90 days.

MATERIALS AND METHODS
Fresh cow dung was procured from the abattoir in the local market in Nsukka town. The food items such as rice, beans, flavouring agent- seed and white yam were purchased from the local market while eggs were bought from the poultry house at the National Centre for Energy Research & Development. University of Nigeria, Nsukka. Other materials utilized were pressure gauge, hosepipes, thermometer (-10-110°C), digital pH meter (Jenway3510), measuring tape, wooden ladder, five medium sized "Tower branded" pots, biogas burners constructed locally.

Measurement of the fixed dome biogas plant.
Using the wooden ladder, the insides of the plant was thoroughly cleaned with water and measurement was taken with a standard measuring tape. The sketch of the plant with simple formula for the calculations of its volume is shown in the figure below:

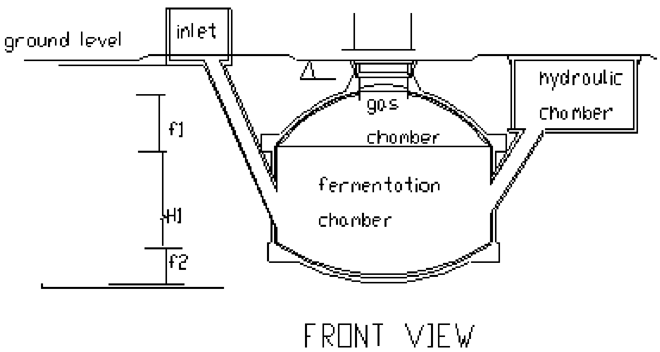

Fig 1: $11M^3$ Chinese Fixed Dome Biogas Plant.

On the sketch above $f_1 = 0.65m$, $H_1 = 1.01m$ and $f_2 = 0.36m$.

The equations used in deriving the volume of the digester are given as;

$$v_1 = \frac{\pi}{6} f_1 (3r^2 + f_1^2)$$

$$v_2 = \pi r^2 H_1$$

$$v_3 = \frac{\pi}{6} f_2 (3r^2 + f_2^2)$$

Volume of Digester = $v_1 + v_2 + v_3$

Where;
v_1 = volume of upper arc (gas chamber)
v_2 = volume of fermentation chamber
v_3 = volume of lower arc
r = radius of cylinder, H_1 = height of fermentation chamber, $f_1$and f_2 = height of upper and lower arc.

Analyses of Wastes
Physicochemical Analysis
Ash, moisture and fiber contents of the undigested agro-industrial wastes were determined using AOAC (1990) method. Fat, crude protein and nitrogen contents were determined using soxhlet extraction and Micro-Kjedhal method described in Pearson (1976). Energy content analysis was carried out using AOAC method described in Onwuka (2005). Total and volatile solids were determined using Renewable Technologies (2005).

Charging Of the Biogas Plant and Cooking Tests.
This followed immediately after the measurement to enable cooking tests to be carried out. A 2000kg of the cow dung was mixed with 4000kg of water (giving a waste to water ratio of 1:2). The waste slurry was charged up to ¾ of the digester leaving ¼ head space for gas storage and collection. The digester content was stirred adequately and on a daily basis throughout the retention period to ensure homogenous blend of the waste slurry and dispersion of the microbes in the entire mixture. Gas production measured in dm^3/kg. TS was obtained by the displacement of water by the gas. The food items were cooked on a daily basis for at least one week after which each cooking was repeated for the next two more weeks.

RESULTS AND DISCUSSION
Table 1: Results of volume of gas and pressure at full capacity

Volume (L/kg.TS)	Pressure(bar)
2250	110mmHg=> 0.147

Table 1 shows the actual volume of gas produced at full capacity of the digester with its pressure at 0.147 bar (0.145 atm). This indicates that the pressure of biogas is very low (below 1 atmosphere). This could account for the difficulty encountered when trying to compress the gas for storage even when the volume of gas is quite high, hence the current trend of using biogas in-situ. The plant or digester performance is usually represented by the volume of gas production from the organic wastes. Cow dung was chosen for the evaluation of this plant because various research findings have affirmed the superiority of cow dung in quality biogas production over other wastes (Odeyemi, 1987, Fulford 1998, Ofoefule et al., 2010). Adequate physicochemical properties are known to favour biogas production. The result of the physicochemical composition of the cow dung utilized for the study showed that the nutrients (fat and protein), volatile solids (which is the biodegradable portion of the waste), energy content and C/N ratio where adequate for effective biogas production (Table 2). The optimum range for C/N ratio has been given to be in the range of 20-30:1 (Dennis and Burke, 2001). This is because the microbes that convert wastes to biogas take up carbon 30 times faster than nitrogen.

Table 2: Physicochemical Properties Of Undigested Cow Dung.

Parameters	Cow dung
Moisture (%)	15.70
Ash (%)	20.10
Fibre (%)	19.50
Fat (%)	11.00
Crude nitrogen (%)	1.40
Crude protein (%)	8.75
Total solids (%)	77.38
Volatile solids (%)	27.01
Energy content (%)	3.76
Carbon content(K/g)	32.92
Carbon: nitrogen ratio(C/N ratio)	23.51

The gas commenced flammable biogas production on the 4^{th} day after charging the digester, while cooking performance tests started the following day from the commencement of flammable gas production.

Table 3 and Fig. 2 shows the results of the cooking performance tests and the volume of the gas utilized for the different food items. Various food items ranging from those that cook over a short period of time to those that take longer time to cook were utilized. It was observed that the various food items took shorter period to cook when compared with the conventional cooking stoves (kerosene, charcoal and firewood) (Table 3). For instance, the cooking of “fio fio” (pigeon pea) and (“okpei”) which normally takes 6 to 7hr to cook (using 3 stone firewood), took 5 hours to cook with biogas. This may be as a result of concentration of the flame and heat to the pot leading to less heat losses which is not normally seen in the conventional cook stoves (Ofoefule *et al*., 2006, Uzodinma *et al*., 2006).

Table 3: Volume of gas consumed at the cooking time daily

Food item	Quantity	Time (hr)	Volume of gas utilized (L/kg. TS)
Eggs, Local rice and Stew	53 20 cigarette cups (5kg) ½ med. Pot stew	3hr 22mins ≡ 3.37	1067.48 ≡ 0.53
Cowpea beans White yam	10 cigarette cups(2kg) 1 tuber (2kg)	2.00	812.22 ≡ 0.41
Pigeon pea (“fio fio”) White yam	18 milk cups (3kg) 2 tubers (5kg)	3.00	1171.90 ≡ 0.56
Local rice and Cowpea(Jellof)	12 cigarette cups (3kg) 4 cigarette cups (0.80kg)	3hr.40min ≡ 3.67	1113.90 ≡ 0.56
Pigeon pea (“fio fio”) White yam	9 milk cups (1.5kg) 2 tubers (3kg)	3hr.49min ≡ 3.82	1160.31 ≡ 0.58
Local rice Stew	10 cigarette cups (2.5Kg) ½med. pot stew	2hrs 50mins ≡ 2.83	1067.48 ≡ 0.53
Cow pea Beans (Portiscum)	10 cigarette cups (2kg)	2hrs 50mins ≡ 2.83	1392.37 ≡ 0.70
Local rice Jellof	10 cups	2.00	928.25 ≡ 0.46
Flavouring Agent (“Okpei”)	8 cups (milk cup)	5.00	2088.56 ≡ 1.04

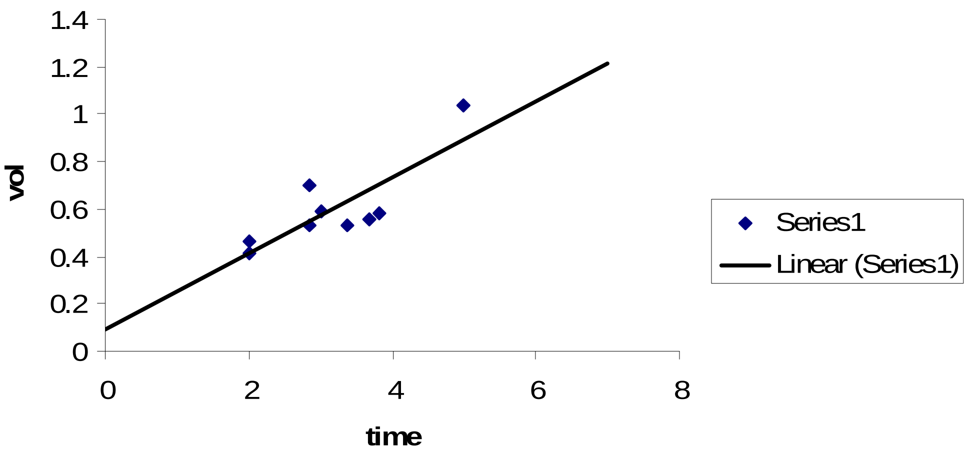

Fig 2. plot of vol against time

Figure 2 shows the quantity of biogas utilized for each cooking day. The quantities of food cooked served more than ten (10) persons at the Research Institute. The figure indicates that the cooking time increases with higher volume of gas generated over a period of time. This indicates that at full capacity, it is estimated that the plant will serve the cooking needs of a family of eight (8) persons for a long time up to a maximum cooking period of 5hr at a stretch and 8hr intermittently depending on the waste type used for the anaerobic digestion.

CONCLUSION

From the investigation carried out, it can be seen that the $11m^3$ biogas plant is in a good working condition and can produce biogas optimally depending on the waste type. It can serve the cooking needs of a family of eight persons on the average. The technology should be sold to institutions and communities that can afford the cost of labour (which involves charging and discharging of wastes including digester maintenance). The comparative study of the performance characteristics between biogas produced from the plant and conventional cook stoves (kerosene, firewood, charcoal and saw dust) will constitute a separate report.

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Received for Publication: 05/02/2011
Accepted for Publication: 14/03/2011

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